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The Strength of Fine-Aggregate Concrete

BY

F. E. GIESECKE, H. R. THOMAS, AND G. A. PARKINSON

BUREAU OF ECONOMIC GEOLOGY AND TECHNOLOGY
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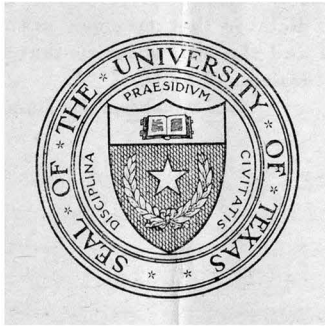
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The benefits of education and of useful knowledge, generally diffused through a community, are essential to the preservation of a free government.

Sam Houston

Cultivated mind is the guardian genius of democracy. . . . It is the only dictator that freemen acknowledge and the only security that freemen desire.

Mirabeau B. Lamar

THE STRENGTH OF FINE-AGGREGATE CONCRETE

I. INTRODUCTION

During the meeting of the Texas Road Builders' Association in Austin, February 18 to 20, 1920, the general discussion of concrete construction developed the facts that in certain sections of Texas the available local concrete aggregate is rather fine; that coarse aggregate can be secured only at a very high cost; and that, under such condition, it might be well to prepare concrete without the use of coarse aggregate, increasing, when necessary, the cement-aggregate ratio so as to secure the desired physical properties in the concrete.

This condition suggested the need for an investigation to determine how the compressive strength of the concrete varies with the relative quantity of cement when the maximum size of the aggregate used in the preparation of the concrete is considerably smaller than that usually employed in concrete construction. Accordingly, four series of tests were made in the manner and with the results described in this bulletin.

II. SCOPE OF THE INVESTIGATION

The object of the investigation was to determine the ultimate compressive strength at 28 days of concrete prepared of fairly well graded aggregate the maximum size of which varied from one-eighth to one-half inch. In addition, tests were made for the purpose of determining something of the effect of additional water on the strength of the concrete, and also the effect of rodding the concrete in which excess water was used. A few tests were made for the purpose of comparing the strength of 6 by 12-inch cylinders with that of the 2 by 4-inch cylinders used for the majority of the specimens.

III. MATERIALS AND METHOD OF TESTING

Aggregate.—The aggregate used consisted of Colorado River sand and gravel, the granulometric composition of which is shown in the accompanying table.

SIEVE ANALYSES OF AGGREGATES

Material Passing the Various Sieves, in Percentage by Weight

Sieve Size	Maximum Size of Aggregate—Inches			
	$\frac{1}{8}$	$\frac{1}{4}$	$\frac{3}{8}$	$\frac{1}{2}$
$\frac{1}{2}$	----	----	----	100.0
$\frac{3}{8}$	----	----	100.0	82.7
$\frac{1}{4}$	----	100.0	75.4	63.5
$\frac{1}{8}$	100.0	76.9	53.0	46.4
14	49.6	39.0	35.2	32.5
28	32.8	29.6	27.1	25.3
48	4.4	4.1	4.0	4.0
100	0.9	0.6	0.8	0.7
200	0.9	0.0	0.0	0.0

Cement.—The cement was a blend of three brands of Texas cement. The water required for normal consistency was 23 per cent. Fineness: 18 per cent retained on No. 200 sieve. Time of set: initial set in 2 hours, 40 minutes; final set in 7 hours. Average tensile strength of 1:3 mortar briquettes made with standard Ottawa sand was 293 pounds per square inch at 7 days and 378 pounds per square inch at 28 days.

Water for Sand.—The quantity of water used in preparing the specimens was based on the granulometric composition of the aggregate according to a system developed in this laboratory by Mr. G. A. Parkinson, Assistant Testing Engineer, this system being used in our regular work unless a different method is specified. By a series of experiments Mr. Parkinson determined, for example, that for a sand passing a No. 40 sieve and retained on a No. 50 sieve an apparent normal consistency was obtained when the mixing water was 8.5 per cent of the weight of the sand, in addition to the water which was used for the cement and which

amounted to 23 per cent (normal consistency) of the weight of the cement. Other proportions were determined in a similar way for sands of other degrees of fineness. The final result is shown in Figure 1, in which the percentage (by weight) of mixing water is plotted against the mean diameter of the grains of the aggregate, the mean diameter being taken as the mean diameter of the sieves passed and retained on. Knowing, then, the sieve analysis of the aggregate, the quantity of mixing water may be determined from the curves given. In this bulletin, the specimens made up with water determined in this way will be referred to as having normal water content.

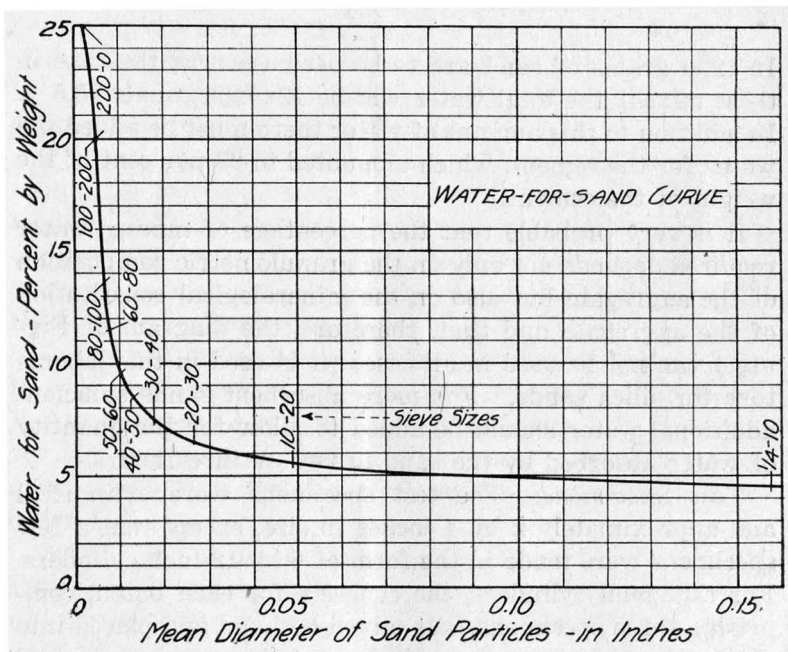


FIG. 1.—Water-for-sand curve, showing amount of water added for sand, based on sieve analysis

For example, the water for the $\frac{1}{8}$ -inch maximum aggregate was computed as shown in the following table for a total weight of 100 grams (or pounds) of aggregate.

Sieve Passed	Number Retained	Weight of Sand Between Sieves	Water, in Percentage of Weight	Weight Required
¾	10	37.7	5.0	1.89
10	20	19.4	5.5	1.06
20	30	20.5	6.5	1.33
30	40	12.2	7.5	0.92
40	50	6.1	8.5	0.52
50	60	1.6	9.5	0.15
60	80	1.0	11.5	0.12
80	100	0.5	13.5	0.07
100	200	0.5	20.0	0.10
200	---	0.5	25.0	0.13

Total water for sand-----6.29 g. (lb.)

If 1200 grams of sand are to be used (as was the case in these mixes) the total water will be 12×6.29 , equals 75.5 g. In addition to this amount of water there must be added the water for the cement, which amounted to 23 per cent of the weight of the cement.

It is very probable that the percentage of mixing water required depends not only on the granulometric composition of the aggregate but also on the mineralogical constitution of the aggregate and that, therefore, the diagram of Figure 1 can not be used in all cases; it is used in this laboratory for silica sands. For more absorbent sands sufficient additional water should be added to allow for the quantity of water absorbed by the sand in two or three hours.

Test Specimens.—The test specimens were cylindrical and approximately 2 by 4 inches in size, except that a few specimens were made in the form of 6 by 12-inch cylinders. For the small cylinders, the concrete for each batch, comprising three specimens, was mixed by hand and placed into the molds in layers of one inch, each layer being tamped with a steel tamp one inch in diameter and weighing about three-fourths pound. This method is the one recommended by the American Society for Testing Materials in their tentative standard for compressive tests of mortars. In making the 6 by 12-inch cylinders, the material for a single specimen was mixed by hand with a trowel in a shallow pan.

The molding of these cylinders was similar to the method used for the smaller ones, except that a larger tamping bar was used, and that the material was tamped in 3-inch layers. At the time of making these specimens it was felt that it was impossible to secure as thorough mixing with a trowel as was possible when the mixing was done with the hands, and the testing of these specimens showed this to be the case, as will be seen later.

The 2 by 4-inch cylinders were stored in a damp-closet for 24 hours at the end of which time they were removed from the molds and stored in water for 27 days. The larger cylinders were capped with a glass plate to prevent drying out and were left in the molds for 24 hours at the end of which time they were removed from the molds and stored in water for 27 days. Before testing, all cylinders were capped with plaster of Paris.

Four series of specimens were prepared, differing from each other in the maximum size of the aggregate, the sizes being $\frac{1}{8}$, $\frac{1}{4}$, $\frac{3}{8}$, and $\frac{1}{2}$ inch. In each series, varying cement-aggregate ratios were used so that the resulting mixes varied from fairly lean to very rich. For each mix, three specimens were made.

In order to be able to compare the results obtained with the 2 by 4-inch specimens with those obtained with 6 by 12-inch specimens, one 6 by 12-inch specimen was prepared for each series, using the mix in each case that corresponded approximately to ten sacks of cement in a cubic yard of concrete.

Since it is not practicable to prepare concrete in the field with as little mixing water as was used in this investigation, one of the mixes of each series was duplicated, using, however, 30 per cent more water than in the normal mix. The mix chosen for these tests was that corresponding to practically ten sacks of cement in a cubic yard of concrete. The resulting concrete was at wet as could conveniently be worked on the glass mixing plate.

It has been found in this laboratory that concrete, particularly when it contains excess water, can be materially

improved by rodding after it has been deposited in the forms. To obtain additional information on the increase in strength due to rodding, the specimens mixed with 30 per cent excess water were made in duplicate, half of them being tamped and half rodded. The rodding consisted of forcing a $\frac{1}{4}$ -inch pointed steel rod into the concrete as it was being placed in the molds, and afterwards at intervals of 30 minutes. Each rodding was continued for 15 seconds, during which time about 20 strokes of the rod were made. The specimens containing 30 per cent excess water were rodded six times. It should be noted that as the water rose to the surface due to rodding, it was poured off instead of allowing it to be re-absorbed by the concrete.

Supplementary Tests.—After having tested the specimens mixed with excess water it was found that the results for the series in which the $\frac{1}{8}$ -inch maximum aggregate was used differed so much from those of the other series that it was decided to disregard the results for that series and to repeat the entire set of tests in which excess water was used.

In repeating this series, 60 specimens were prepared; twelve of this number were mixed with the normal quantity of water for reference; 24 were mixed with 30 per cent excess water and 24 with 40 per cent excess water. Of the 48 specimens mixed with excess water 12 of each group were tamped and 12 of each group were rodded exactly as described for the original series with excess water, except that the number of roddings was increased from six to eight in every case.

The 60 specimens of this series were prepared as described for the original series except that each specimen for the normal water content was mixed separately, while those mixed with excess water were made in pairs, one of which was tamped and the other rodded. The three specimens of each group were prepared on different days.

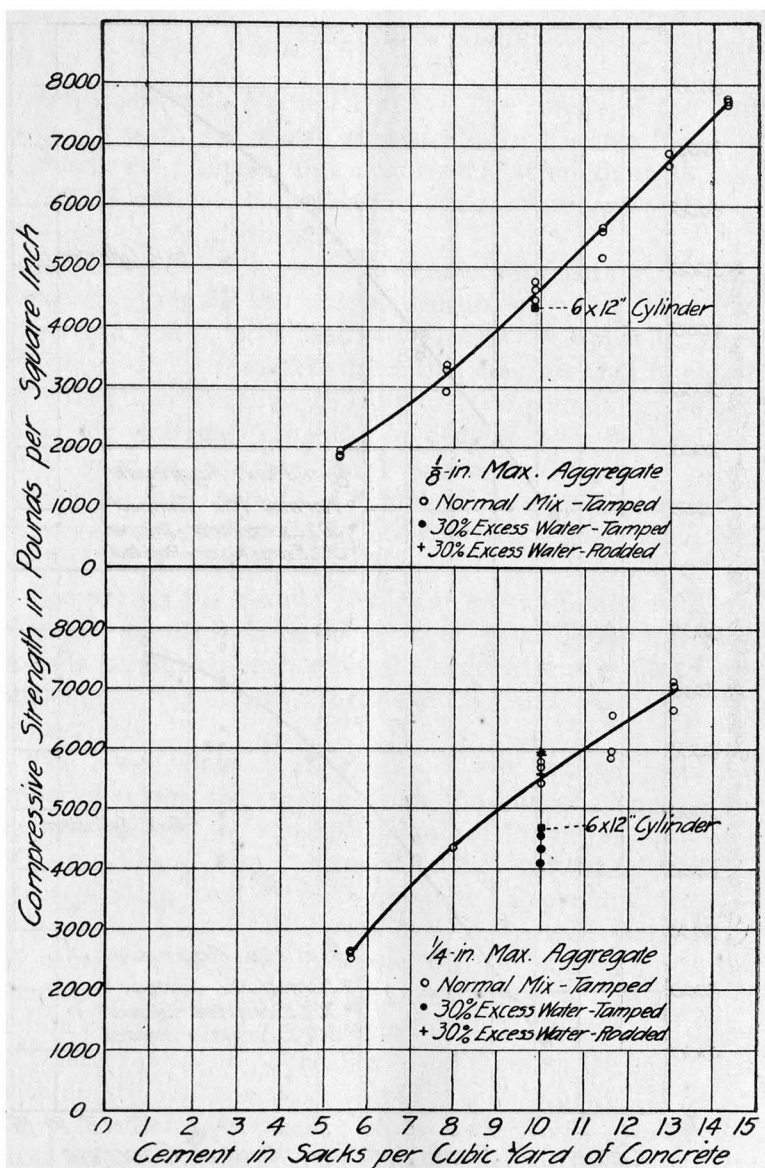


FIG. 2.—Showing the relation of the compressive strength of concrete to the relative quantity of cement

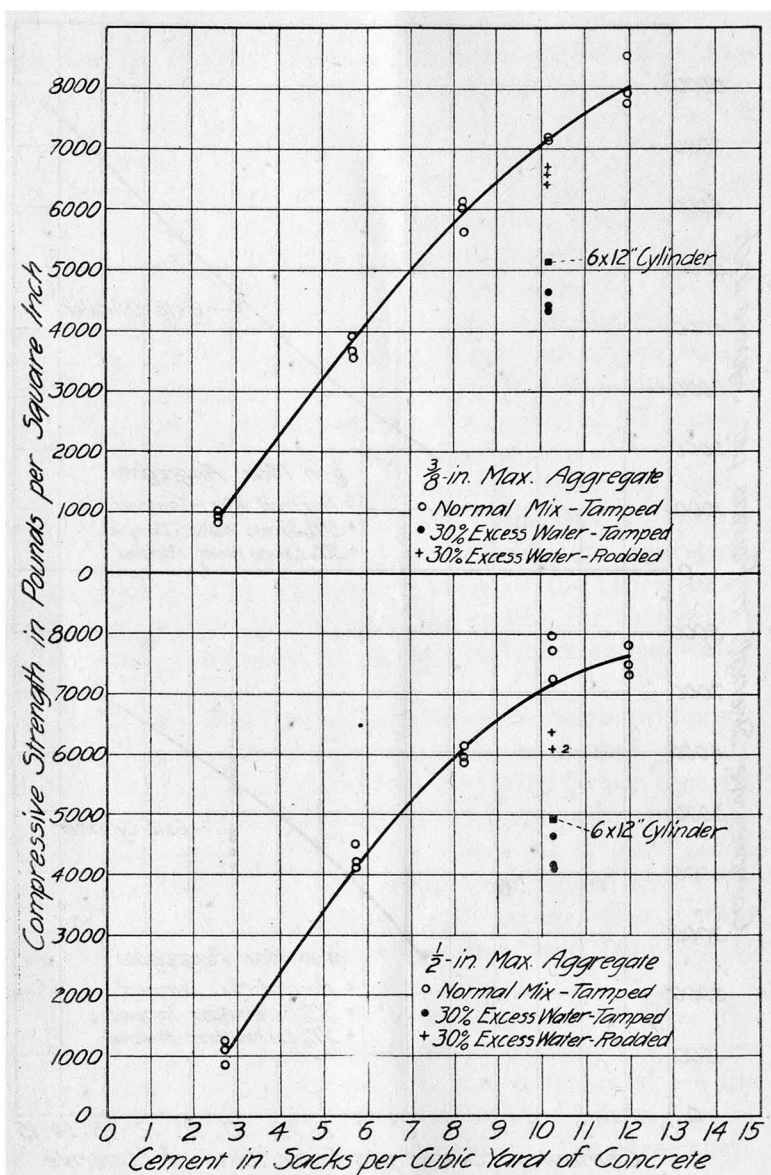


FIG. 3.—Showing the relation of the compressive strength of concrete to the relative quantity of cement

IV. RESULTS OF TESTS

Specimens with Normal Water.—The results of the four series of tests are shown graphically in Figures 2 and 3, in which the ultimate unit compressive strength at 28 days is plotted against the number of sacks of cement contained in a cubic yard of concrete.

For ease of comparison, the results obtained for the four sizes of aggregate and normal amount of water, shown in Figures 2 and 3, have been replotted in the upper diagram of Figure 4. It is evident from this diagram that to obtain an ultimate strength at 28 days of 3000 pounds per square inch, for example, 7.5 sacks of cement must be used per cubic yard of concrete if the aggregate is graded up to one-eighth inch, and 6.1, 4.8, and 4.6 sacks per yard if the aggregate is graded up to one-fourth, three-eighths, and one-half inch, respectively.

Comparing the results obtained for the 8-sack mix, for example, we find strengths of 3300, 4400, 5700, and 6000 pounds per square inch when the aggregate is graded up to one-eighth, one-fourth, three-eighths, and one-half inch, respectively.

The lower diagram of Figure 4 was derived from the upper diagram by reading from the curves, for a given cement content, the strengths obtained for the several sizes of aggregates. These values were then plotted against the corresponding sizes of the aggregate. From this diagram it is evident that, up to a certain point, for a given quantity of cement a stronger concrete will be obtained for the coarser material than for the finer aggregate. In order to obtain concrete of a given strength it is evidently a question of whether it would be cheaper to use the finer local material with additional cement, or to pay a higher price (if necessary) to obtain a coarser aggregate which will give the desired strength with a smaller proportion of cement.

In using these values it must be remembered that the strength of field concrete is generally less than that of laboratory concrete. But from comparative tests made a few

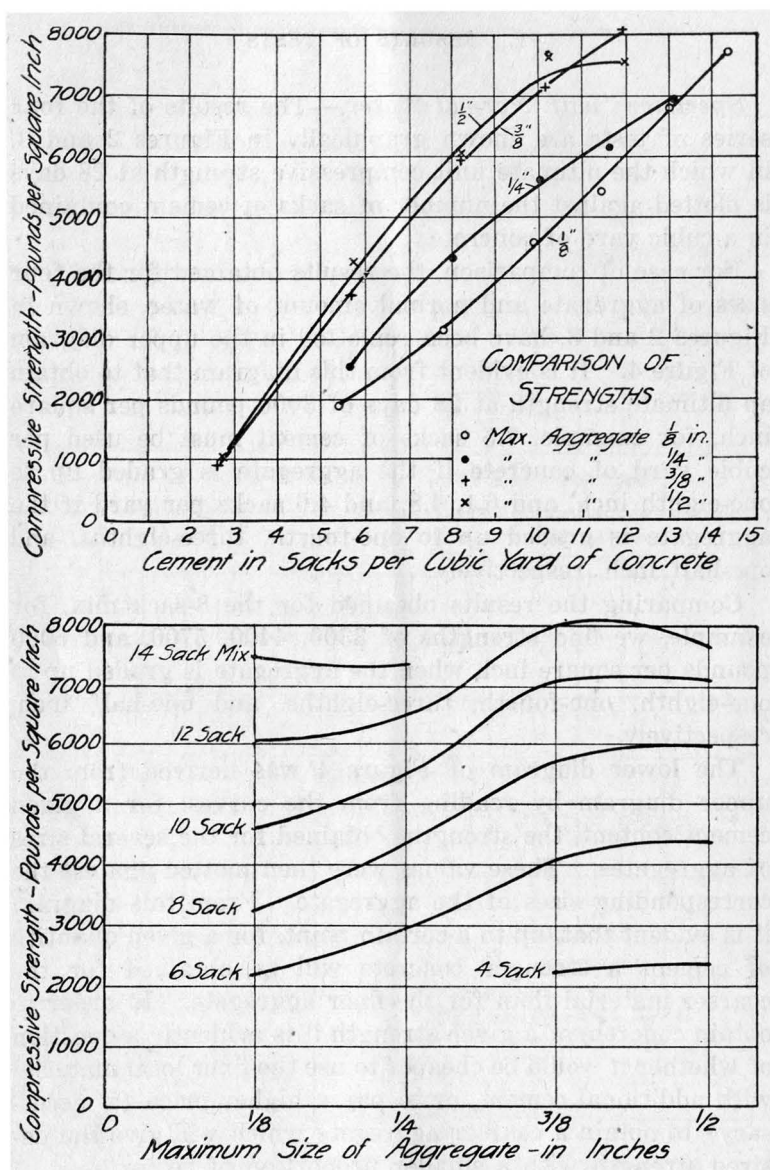


FIG. 4.—Curves showing the variation in the strength of concrete with the variation in the maximum size of aggregate and the relative quantity of cement

years ago by this laboratory it is believed that builders should be able to secure a strength in their field concrete which is at least two-thirds of that which would be obtained with the same materials under laboratory conditions. That is, if it is desired to determine the amount of cement which would be necessary to produce a 2000-pound concrete under field conditions, it would be necessary to take from this diagram the amount of cement necessary to produce a strength of 3000 pounds per square inch under laboratory conditions. It should not be forgotten, however, that the diagram may not apply if the grading of the material is different from that of the aggregate used for these tests or if the character of the aggregate is different from that here reported.

In all important work it is advisable to prepare comparative specimens of the actual aggregate or aggregates to be used, with varying proportions of cement, in order to determine the most economical proportions.

The amount of water used should be accurately controlled and should be the minimum which will produce a workable mix.

Large Specimens.—In Figures 2 and 3 are also shown the strengths of 6 by 12-inch specimens. It should be noted that the strengths of these specimens were less than for the corresponding 2 by 4-inch specimens, ranging from 6 per cent less for the $\frac{1}{8}$ -inch maximum aggregate to 32 per cent less for the $\frac{1}{2}$ -inch maximum aggregate. As has previously been pointed out, this was evidently due to the inferior mixing produced by trowel to that produced by hand.

Specimens with Excess Water; First Series.—It is also apparent from Figures 2 and 3 that the average strength of the tamped specimens in which 30 per cent excess water was used was about 21 per cent less than the normal mix for the $\frac{1}{4}$ -inch maximum aggregate, 38 per cent less for the $\frac{3}{8}$ -inch maximum aggregate, and 40 per cent less for the $\frac{1}{2}$ -inch maximum aggregate.

Comparing the rodded specimens containing 30 per cent excess water with the normal tamped specimens, we find that the rodded specimens are 6.0 per cent stronger than the

normal for the $\frac{1}{4}$ -inch maximum aggregate, 8.8 per cent weaker for the $\frac{3}{8}$ -inch maximum aggregate, and 14.0 per cent weaker for the $\frac{1}{2}$ -inch maximum aggregate.

Comparing the rodded specimens containing 30 per cent excess water with the tamped ones containing 30 per cent excess water, we find that the rodded specimens are 35 per cent stronger than the tamped for the $\frac{1}{4}$ -inch maximum aggregate, 46 per cent stronger for the $\frac{3}{8}$ -inch maximum aggregate, and 43 per cent stronger for the $\frac{1}{2}$ -inch maximum aggregate.

Specimens with Excess Water; Supplementary Series.—In the upper diagram of Figure 5 are given results of the supplementary tests. Each point indicated is the average for three tests. It will be noted that three curves are given: one for the specimens made with the normal amount of water, one for specimens made with 30 per cent excess water and tamped into the molds, and one for specimens made with 30 per cent excess water and rodded as already described.

In the lower diagram of Figure 5 are given curves for tests of the specimens made with 40 per cent excess water, both rodded and tamped. For ease of comparison, the curve for normal water content has been repeated from the upper diagram.

Comparing the rodded specimens made with 30 per cent excess water with the tamped specimens made with normal water content, we find that the rodded specimens are 15 per cent stronger than the normal for the $\frac{1}{8}$ -inch maximum aggregate, 5 per cent stronger for the $\frac{1}{4}$ -inch maximum aggregate, and 3 per cent weaker for both the $\frac{3}{8}$ and $\frac{1}{2}$ -inch maximum aggregate.

Comparing the rodded specimens made with 30 per cent excess water with the tamped specimens with 30 per cent excess water, we find the rodded specimens 32 per cent stronger than the tamped for $\frac{1}{8}$ -inch maximum aggregate, and 34, 37, and 30 per cent stronger for $\frac{1}{4}$, $\frac{3}{8}$, and $\frac{1}{2}$ -inch maximum aggregate, respectively.

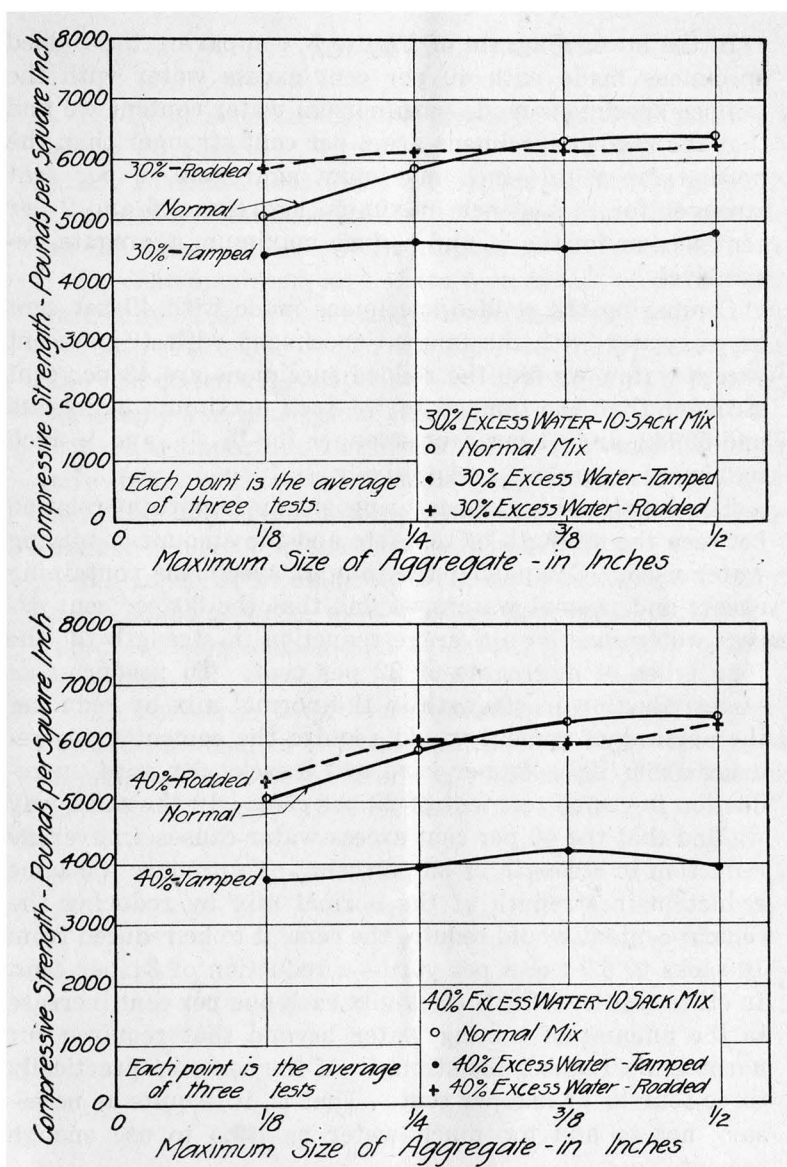


FIG. 5.—Curves showing the effect of excess water, with and without rodding

In the lower diagram of Figure 5, comparing the rodded specimens made with 40 per cent excess water with the tamped specimens made with normal water content we find that the rodded specimens are 6 per cent stronger than the normal for the $\frac{1}{8}$ -inch maximum aggregate, 2 per cent stronger for the $\frac{1}{4}$ -inch maximum aggregate, 6 and 2 per cent weaker for the $\frac{3}{8}$ and $\frac{1}{2}$ -inch maximum aggregate, respectively.

Comparing the rodded specimens made with 40 per cent excess water with the tamped specimens with 40 per cent excess water, we find the rodded specimens are 43 per cent stronger than the tamped for $\frac{1}{8}$ -inch maximum aggregate and 53, 42, and 61 per cent stronger for $\frac{1}{4}$, $\frac{3}{8}$, and $\frac{1}{2}$ -inch maximum aggregate, respectively.

The supplementary tests bring out an important relation between the strength of concrete and the amount of mixing water used. Comparing the tamped specimens containing excess and normal water, we find that the 30 per cent excess water causes an average reduction in strength for the four types of aggregate of 22 per cent. To produce this same reduction in strength in the normal mix by reducing the amount of cement would require the cement to be reduced from 10 sacks per yard to 7.8 sacks per yard—a reduction in cement content of 22 per cent. In the same way we find that the 40 per cent excess water causes an average reduction in strength of 33 per cent. To produce the same reduction in strength of the normal mix by reducing the cement content would require the cement to be reduced from 10 sacks to 6.9 sacks per yard—a reduction of 31 per cent. In other words, for a 10-sack mix each one per cent increase in the amount of mixing water beyond that required for normal mix reduces the strength of the concrete practically three-fourths of one per cent. That is, it is quite as necessary not to add too much water as it is to use enough cement.

V. SUMMARY OF RESULTS

1. Good concrete can be prepared without the use of coarse aggregate.

2. To obtain concrete of a given strength with given materials, the relative quantity of cement must be increased as the maximum size of the aggregate is decreased.

3. The maximum size of the aggregate, when not determined by other factors, should be determined so as to obtain the lowest possible cost of the concrete, taking into account the cost of the aggregate and that of the quantity of cement necessary for the type of aggregate used.

4. On important work it is desirable to make comparative tests, with various cement-aggregate ratios, of the available aggregates in order to determine which aggregate should be used and the most economical mix.

5. In order to obtain a concrete of maximum strength, the amount of water used must be the minimum which will produce a consistency such that the concrete can be placed properly.

6. The strength of concrete can be increased materially by rodding it after it has been deposited in the forms, particularly if the water which is rodded out of the concrete can run off freely as it comes to the surface.

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